

Pedagogic Principles for an Immersive Learning Environment for Process Engineering

Christine Norton, Ian Cameron, Caroline Crosthwaite

The University of Queensland, Brisbane, QLD

c.norton@uq.edu.au

Nicoleta Balliu, Moses Tade

Curtin University of Technology, Perth, WA

David Shallcross

The University of Melbourne, Melbourne, VIC

Andrew Hoadley

Monash University, Melbourne, VIC

Geoff Barton, John Kavanagh

The University of Sydney, Sydney, NSW

***Abstract:** This work differentiates itself from most educational based multimedia resources by catering for two distinct audience groups. The first group is undergraduate process engineering students in a number of Australian institutions, whereas the second group represents operational staff at the industrial facilities covered by the interface. This presents challenges in pedagogy, educational pitch, industrial relations and project management. It has also added a sales driver to the project as we market the resource to industry as an operator training resource.*

The learning environment is based around spherical imagery of real operating plants coupled with interactive embedded activities and content. This Virtual Reality (VR) learning tool has been developed by applying aspects of relevant educational theory and proven instructive teaching approaches. Principles such as constructivism, interactivity, cognitive load and learner-centred design have been central considerations when constructing and structuring this resource. Structural challenges include determining a framework for the basic environment, the repository for the VR and activities, as well as the development of a learning platform arrangement to support self-directed learning in the interface. Some of the system's current functionality is demonstrated through snapshots of the screen configuration. Future developments within the interface are revealed.

Introduction

This project addresses the parallel needs of university and industry through delivery of a set of virtual process plants embedded with training and learning resources.

Within university, current undergraduate engineering students in chemical, process and related disciplines often lack industry exposure. Opportunities for providing visual context for process theory in real operating systems are increasingly less accessible to students. Costs, litigation concerns as well as logistic constraints make both plant operators and university staff hesitant to conduct large scale plant tours. Additionally, the demise of most industry-based cadetships means students have forfeited the opportunity to see engineering in practice. This therefore leaves a significant gap in the conceptual understanding of the current process engineering undergraduate.

For university students, this environment brings the real plant to the user through a set of virtual reality (VR) immersive environments. These environments enhance insight and understanding by providing:

- A real engineering context within the different plants
- Relevant activities and information pieces embedded within the VR imagery
- An exploratory platform to discover and investigate at the individual's own pace.

(Cameron *et al.*, 2005)

In industry, there is a genuine need to establish effective operational training resources which deliver a consistent message to operations and engineering staff. With round the clock operations in most process plants, there is also a desire to provide a learning platform which is accessible and available 24 hours a day. Obviously a learning structure which reduces the requirement for trainer supervision, without diluting the key learning outcomes, provides industry with undeniable cost and training benefits.

Industrial staff can utilize the environments to:

- Showcase their industry to the general public
- Provide the basis for general site inductions
- Conduct operator training on specific equipment
- Introduce process engineering theory in a familiar setting
- Shed light on the pieces of process equipment generally regarded as "black boxes" by process operators.

Through application of this learning tool, industry is given the opportunity to provide a level of consistency in their operator training, through an easily accessible platform, which does not require intense supervision or support.

The application of VR technology in this setting supports visualization of systems in a sphere which is not intrusive on the operational plant but offers experiential learning opportunities without risk of serious consequences. With its modified view of reality, users are allowed to explore beyond traditional boundaries into pieces of equipment and their operation. Immersion in the VR leads to a sense of "being there" which is associated with genuine psychological learning benefits. Within this setting, users are able to direct their own learning in a style espoused in constructivist philosophies and by learner-centred practices. The visual strengths offered by VR are strongly aligned with the learning preferences of the users and support easy translation of the dynamic content into imagery suitable to the audience.

A prototype VR system commenced development at The University of Queensland during 2005 (Cameron *et al.*, 2005). The development of this VR immersive environment prototype system and the on-going associated activities has been supported by BP (Bulwer Island) Refinery Brisbane, Australia. The project team has received feedback from key stakeholders regarding this prototypic environment and is currently in the process of modifying the environment to improve usability and add the increased functionality requested. Development of a second immersive environment covering Coogee Energy's methanol plant based in Victoria, has commenced. Showcases of the prototypic environment to other industry groups has generated interest from Alcoa (WA), BHP Biliton (Vic), VISY (NSW), Qenos (NSW) and Veolia Water Australia (NSW) and may result in the addition of more industrial applications to the interface to create a library of VR immersive environments.

Users

A common fault with computer based learning environments is that they fail to cater for the diversity of their users. It is not easy to anticipate or suit different levels of processing ability, learning mode preferences and different methods of use simultaneously (Judith and Julianne, 2003), (Plass *et al.*, 2003). This leads most designers towards a user-centric approach. In user-centred systems, the user is directing their own passage through the medium, at their own pace and using tools that are suited to their needs and preferences.

In the development of educational multimedia, the principles of user-centred design are difficult to apply because the end users of the resource are not experts in the subject matter. When designing

computer based learning programs for students, to combat this issue, there must be considerable learner profiling performed.

Target Audience

A potential stumbling block for this project is the breadth of the application's target audience. This learning tool has been designed to assist two significantly different target groups: operations personnel and undergraduate engineering students. The operations personnel differ from site to site and so does the profile of the undergraduate engineering students as you move from university to university around Australia.

Our primary target audience is undergraduate process engineering students, initially, in Australian universities. The application can be used by first year students through to final year students. Undergraduate students have a good theoretical background but often lack an appreciation of scale, operation and complexity.

Process operators are the exact opposite. They have a genuine knowledge of operation and its response to change but they lack a deeper understanding of the theory or rationale behind the observed effects.

In order to rationalize these two distinctly different sets of needs within a single system, the immersive system has sort to use learning aids which are suitable to both target groups. Preference for visual rather than textual or graphical explanations is common to both audience groups. Since the engineering content possesses dynamic concepts, which are appropriately handled by visualisations and animations (Ebner and Holzinger, 2006), spatial and visual imaging of content is employed in this resource. When presenting information in embedded activities, neither an operational nor a theoretical background is assumed, so both these aspects are addressed in each learning tool. This supports understanding from the two different perspectives of the key audience groups.

The choice of a VR immersive environment as a basis for this learning resource therefore suits the styles and preferences of our key audience groups and supports the visualizations and animations which are the best mechanisms for conveying engineering theory and practice.

Pedagogy

Research has been conducted into relevant educational theory and practices on which to base learning resource development, how best to structure the base level environment which houses the embedded learning resources and then how to leverage a set of environments into a learning platform.

Educational theory and practices

Unfortunately educational theory behind such multimedia applications has not been developed as rapidly as the technological capacity to build it. Often the design of such resources is driven by the technical potential rather than validated educational theory. In an attempt to circumvent this complication, we have attempted to base the design and development decisions on educational theory and proven practices. The following section gives a brief overview of the relevant theory and its application in e-learning environments.

Applicable concepts, principles, practices and theories include:

- Concept of constructive learning
- Theory of cognitive load and management strategies
- Dual code theory
- Principles of instructional design of educational multimedia

Constructive learning is a process by which students build a framework networking their knowledge into a self-constructed map. This is postulated to be characteristic of meaningful learning such that concepts are genuinely embedded when learners select and structure their own learning and integrate it with their current knowledge (Mayer and Moreno, 2002). However, an overall framework in which the learning takes place can be a very useful starting point.

Learning is said to be limited by processing power. This gives rise to a gamut of educational theory related to cognitive load. Ploetzner and Lowe (2004) believe that individuals possess a maximum

processing capacity which limits the transmission of information through learning channels. Exceeding maximum processing power results in cognitive overloading which in turn can lead to under-processing of information (Mayer and Moreno, 2002).

When teaching methods consider cognitive load, the management strategy involves reducing extraneous load (mental effort required to manage how information is presented) and increasing germane load (mental energies directed towards learning, structure and embedding knowledge) while acknowledging the diversity of student's intrinsic cognitive load (mental capacity and pre-knowledge). (Bodemer *et al.*, 2004)

Dual code theory was discussed by Mayer and Moreno (2002). They enhanced the concept of cognitive load by theorising that there are different processing systems for verbal and visual materials. Each coding channel has limited cognitive load capacity but they operate independently of each other. When processing information, two mental models are formed simultaneously, one on the basis of the aural channel and the second through the visual channel. These aural and visual models are integrated with prior knowledge to generate conceptual understanding.

When dual code theory was overlaid on cognitive load theory, it gave rise to a number of principles which form the basis of instructional design in educational multimedia. These are best documented by Mayer and Moreno (Mayer and Moreno, 2002, Mayer, 2003, Moreno and Mayer, 2000), although tested and proven by a number of other authors (Plass *et al.*, 2003, Dunsworth and Atkinson, 2005, Atkinson *et al.*, 2005, Schwan and Riempp, 2004). These principles include directions on methods of presentation of educational material to best ensure the concepts are embedded. Examples include the Multiple Representation Principle which dictates that explanations in words and pictures are better than words or pictures alone and the Modality Principle which indicates that auditory narration alone is better than on-screen text accompanied by narration.

Developing educational resources

Some key principles of structuring a multimedia resource include:

- When presenting information, knowledge accessed, processed, interpreted and constructed by the individual is more likely to be embedded than that which is force-fed.
- Teaching becomes an act of supporting, motivating and guiding rather than delivering facts and presenting knowledge. This model of instruction means education needs to help learners collect tools to become better self-directed learners rather than simply teach facts and figures. (Nulden, 2001)
- Applying a constructivist model, whereby the student is given access to cognitive tools which extend their learning potential beyond their abilities - in effect, scaffolding their ability to accumulate and process knowledge. These tools also assist by supporting cognitive processing, sharing cognitive load or allowing users to visualise, analyse, interpret, rationalise and develop information (Sedig *et al.*, 2005). Such an approach requires careful consideration and implementation.
- Employing user-centred design philosophies as practiced in the development of Human-Computer Interfaces (HCI). In educational resource development, the end-user is effectively the learner, who is generally regarded as a content and user novice. Principles of user-centred design have to be modified to make allowances for this difference in experience. This gives rise to learner-centred design philosophies (Blythe, 2001). With the student central to the design, the learning premise is based on self-directed exploratory research of the interface. Since self-directed learning is more personally meaningful, it is hoped that the teachings are more likely to be embedded. When focusing the interface on the user and allowing them to direct their own path through the medium, it is possible to negate the difficulties created by designing for a diverse group of users.
- Utilising technology which complements the user and does not intrude upon the work of the human in the interface. Not only should technology be invisible to the user, it should

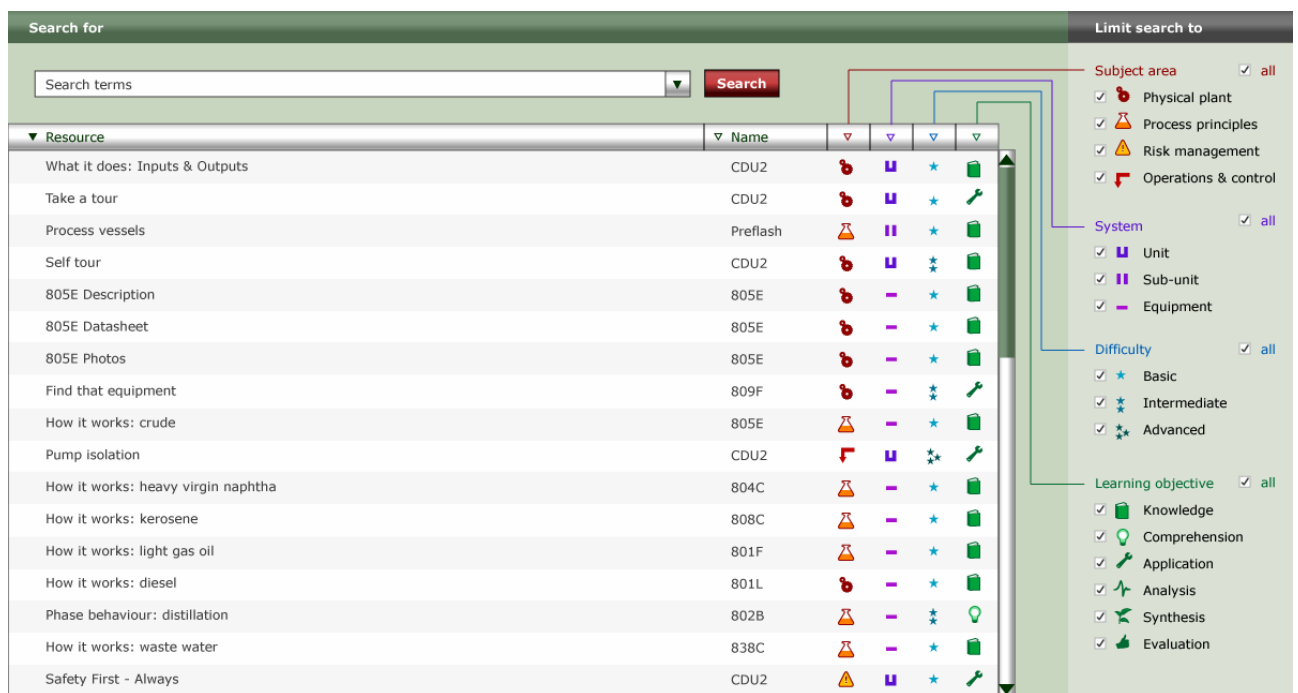
compensate for deficiencies in expertise and therefore reduce extraneous cognitive load while providing cognitive relief (Hegarty, 2004).

- Prototyping and usability testing of the resource with the learners during development to compensate for their lack of involvement in the design phase.

Basic environment structure

To encourage self-directed exploratory research of the interface, a menu structure embedded in the VR has been selected for the base level environment structure. In investigating the VR interface, a learner can highlight all equipment with content or activity links associated with them. When the piece of equipment is selected, a right-click of the mouse accesses a description of that piece of equipment, learning resources associated with it or its system and a search page. The search engine offers the ability for learners to follow links to learning resources classified by system variables such as portion of the unit covered, difficulty, subject area and learning objectives. Similarly a user can search through keywords to discover equipment, its features and location within the VR.

Figure 1 Search page



This structure offers the best utilization of the immersive environment's visual strengths. It also alleviates a menu structure, accessed external to the VR, with a branching structure with a number of unpopulated categories. In applying this structure, we are supporting functionality requested by students in usability surveys.

Learning platform options

When a set of immersive environments has been developed, each employing the basic environment structure, we will look at ways to coordinate the environments into a self-directed learning platform characterized by an innovative technology format. Three over-arching learning platform arrangements considered in more detail for this work, which encapsulate key aspects of educational theory and the principles of constructivist e-learning environments include:

- Concept Mapping
- Educational Games
- Problem Based Learning

Concept mapping involves internalising the learning, interpreting and understanding how the concept interacts with the other pieces of existing knowledge and then outputting this knowledge framework explicitly in the form of a map. This requires a deep understanding of the concept and how it fits into

their education. Educators can assess whether meaningful learning has taken place, by simply reviewing the concept map produced.

Concept maps are student-centred learning tools as they present the student's view of their current knowledge network. The process of creating a concept map involves organising information into an internally coherent framework and hence, according to Gros (2002), is, by definition, a constructivist task. Sedig *et al* (2005) concurs, indicating that the process of verbalising cognitive maps is true constructivism in practice.

The learning platform offered by educational games combines strategies used in commercial gaming with those of educational research into motivation and knowledge acquisition (Barab *et al.*, 2005). The strength this combination offers is an experientially based learning opportunity with active participant involvement at an emotional level. According to Barab *et al.* (2005) the key characteristics of educational games include:

- A mythological content. Fantasy is a strong motivating element but must be carefully chosen to appeal to the target audience. If students are permitted to adopt a different persona it can give them anonymity and possibly invigorate their confidence to perform to or beyond their potential.
- Spaces where interaction can take place both with other game players and with the characters or pedagogical agents established in the game.
- A well-defined advancement system based on pedagogically valid educational activities.
- Regalia and rewards which provide performance feedback as well as having motivational effects.
- A home page per student which can act as a repository for work and a record of their progress

In the context of the immersive learning environment it is possible for learners to adopt the position of an operator, supervisor or even designer within the system and carry out tasks related to those roles. Other characteristics within educational games can be adopted and adapted for application into the immersive process engineering system.

Problem based learning (PBL) is based on the theory that learning occurs in the process of solving a complex problem (Gros, 2002). Provided the complexities are authentic, the strength offered by this form of learning is the likeness of the problem setting to that facing a student in the real world. Cognitive tools help build a knowledge construction environment (Lui *et al.*, 2002). Generally through the application of PBL, there is a shift in the roles of the teacher and the student. The student becomes the inquiring, active seeker of knowledge and the teacher the sideline supporter and guide (Pedersen *et al.*, 2002). The teaching challenge then becomes one of provision and timing of support rather than presentation of content. This role-reversal suits the e-learning arrangement offered within a technologically based application such as an immersive environment; however it does have its shortcomings. The success of PBL is undeniably linked to the level of active participation and self-directed learning drive that the student possesses. To encourage participation, the learning environment has to offer a captivating platform, a strong basis for constructive learning and plentiful opportunities to seek assistance and collaborate. These needs are easily catered for in a hypermedia based, computer environment.

Learning Resources

Some of learning applications available in the immersive environment covering Crude Unit Number 2 at BP (Bulwer Island) Refinery, Brisbane are introduced in the following sections.

Take a tour

Users are initially able to take a fully guided and narrated tour or they can choose to take a self-guided tour to move around the plant to any place of interest. This provides a context to other learning activities and also raises awareness of such issues as complexity, layout, breadth of equipment types, interactions between sub-units and the like.

Figure 2 Take a guided tour

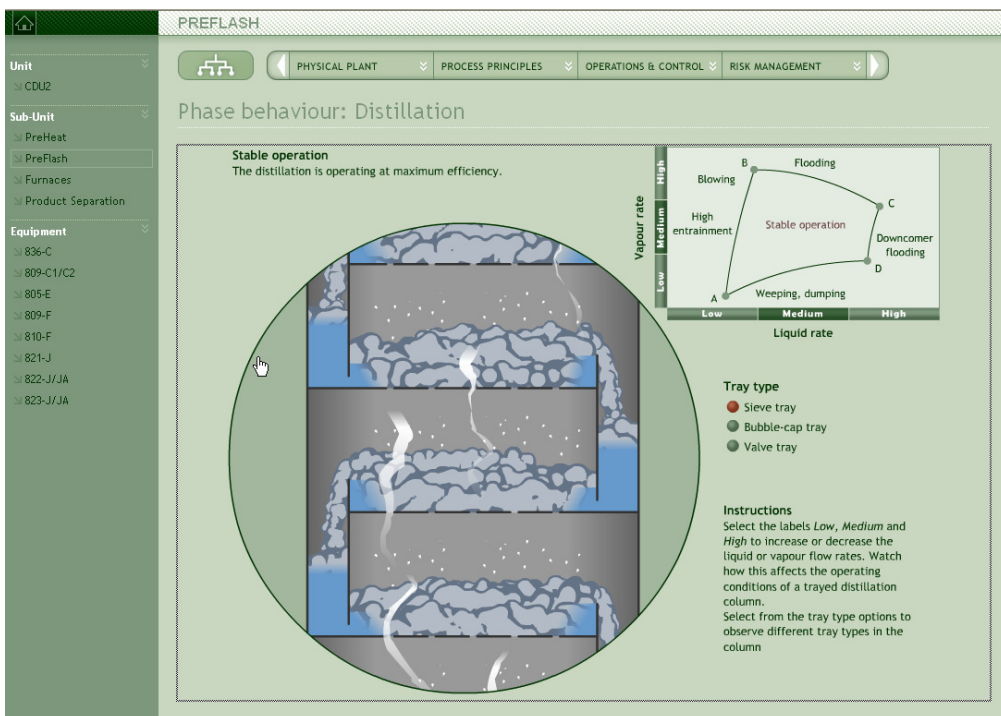


Distillation phase behaviour

An informative animation explores the theory of distillation. Within this activity a user can manipulate vapour and gas flows and tray type and see the effects that this has on liquid-vapour contact regimes. Dynamic models of distillation have been formulated to enable students to manipulate key system variables and assess responses. These are still to be linked to the VR.

Using dynamic models also allows the learner to act as a designer, changing basic design parameters within the separation column and then observing the resultant change in system behaviour.

Figure 3 Distillation phase behaviour



Pump isolation

In this activity, the user performs a pump shutdown by mimicking all the actions required within the VR environment. By turning valves, securing spare pumps and opening drains, the user appreciates the detail required by the procedure and the critical importance of each step. They are also able to realise the checking mechanisms and the regimented correctness facilitated by the GRAFCET procedure structure.

Figure 4 Pump isolation activity



P&ID to VR referencing

From the process and instrumentation diagram (P&ID), a user is able to select a piece of equipment. This referencing tool then links this equipment symbol to its VR image (Figure 5). When you re-click on the piece of equipment in the VR, it will return to the P&ID highlighting the equipment's symbol. In this way the learner builds an understanding of the 2D representation and its relation to the 3D physical world.

Future Developments

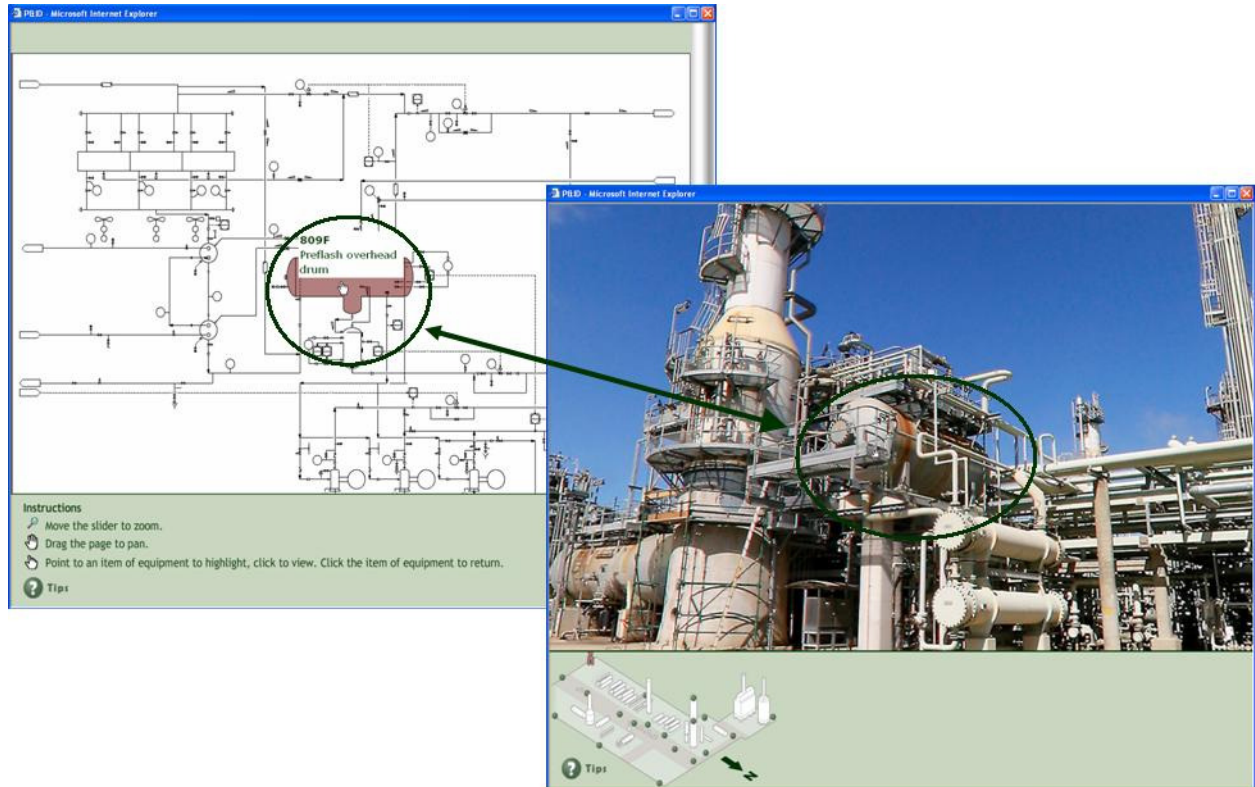
Activities under construction

We will continue to enhance the virtual process plant with the addition of several new activities. These activities include:

- A Wonder-why tour which explores the intricate design of specialised equipment, layout arrangements, piping configurations and design choices and then questions students about their rationale and basis.
- Risk management activities including an explosion simulation which looks at the role of confinement in explosion impacts (Figure 6).
- Pinch analysis of the preheat exchanger train in an attempt to determine the underlying design assumptions made.
- A flow-sheeting exercise in which students generate the process flow diagram from a process description.

- Performing mass and energy balances over a heat exchanger network to determine the cause of product quality issues.
- A GRAFCET formulation activity in which a written procedure to shutdown a heat exchanger is transformed into a GRAFCET diagram.
- The generation of a temperature versus enthalpy chart describing the passage of kerosene through the distillation column from the flash zone to the draw off point.

Figure 5 P&ID to VR referencing



Industrial partnerships

Our relationship with BP (Bulwer Island) Refinery is firmly established and has been authenticated by both parties as being of mutual benefit.

We have recently engaged in a similar partnership with Coogee Energy Australia and have commenced development of a second environment covering their methanol plant in Victoria, Australia.

In engaging with industry in partnerships, there have to be some key considerations clarified between the two parties. Before initiating the development an immersive environment, we need:

- to be able to secure site access for photography
- to be provided with content, datasheets and site diagrams
- to select a unit or an element of the process as a focus, which has an appropriate complexity but does not have the complications of licensed technology
- to receive some level of financial commitment in terms of sponsorship with money or resources
- to ensure that industrial sensitivities are not exposed by use of the environment in an university setting.

In the future we are looking to embark on partnerships with members of the following industrial groups: mineral processing, food processing, water treatment and/or paper and pulp.

Figure 6 Explosion simulation case



Conclusion

The learning resource has been well received by student groups, lecturers and course coordinators, industry operators and industry management. Lecturers at the University of Queensland and partner institutions are already applying the resource to aid learning in key control and unit operations courses. BP (Bulwer Island) Refinery has utilized pump isolation exercises to train new operators in basic operating procedures and provided access to the interface for all other operations personnel. Management personnel within the BP Major Hazards group have identified applications for this tool in visualizing the extent of hazardous incidents. It seems the more exposure the system gets in industry and universities, the more applications are discovered for the resource and so momentum around its use is generated and expanding rapidly.

Acknowledgements

We gratefully acknowledge the contributions of the multimedia and instructional design staff at the Teaching and Educational Development Institute (TEDI) at the University of Queensland.

We thank those in the Learning and Development Group at BP (Bulwer Island) Refinery Brisbane for their keen interest and support in the development of this tool.

Financial support for this project has been provided by The Carrick Institute for Learning and Teaching in Higher Education Ltd, an initiative of the Australian Government Department of Education, Science and Training.

References

- ATKINSON, R. K., MAYER, R. E. & MERRILL, M. M. (2005) Fostering social agency in multimedia learning: Examining the impact of an animated agent's voice. *Contemporary Educational Psychology*, 30, 117-139.
- BARAB, S., THOMAS, M., DODGE, T., CARTEAUX, R. & TUZUN, H. (2005) Making learning fun: Quest Atlantis, a game without guns. *Etr&D-Educational Technology Research and Development*, 53, 86-107.

- BLYTHE, S. (2001) Designing online courses: user-centered practices. *Computers and Composition*, 18, 329-346.
- BODEMER, D., PLOETZNER, R., FEUERLEIN, I. & SPADA, H. (2004) The active integration of information during learning with dynamic and interactive visualisations. *Learning and Instruction*, 14, 325-341.
- CAMERON, I. T., CROSTHWAITE, C. A., DONALDSON, A., SAMSUDI, H. & FRY, M. (2005) An Immersive Learning Environment for Process Engineering using Real VR. *CHEMECA Conference (Sept)*. Brisbane.
- DUNSWORTH, Q. & ATKINSON, R. K. (2005) Fostering multimedia learning of science: Exploring the role of an animated agent's image. *Computers & Education*, In Press, Corrected Proof.
- EBNER, M. & HOLZINGER, A. (2006) Successful implementation of user-centered game based learning in higher education: An example from civil engineering. *Computers & Education*, In Press, Corrected Proof.
- GROS, B. (2002) Knowledge Construction and Technology. *Journal of Educational Multimedia and Hypermedia*, 11, 323-343.
- HEGARTY, M. (2004) Dynamic visualizations and learning: getting to the difficult questions. *Learning and Instruction*, 14, 343-351.
- JUDITHE, S. & JULIANNE, L. (2003) Challenges of Web-Based Learning Environments: Are We Student-Centred Enough? IN ZHOU, W. E. A. (Ed.) *Lecture Notes in Computer Science : Advances in Web-Based Learning - ICWL 2003*. Berlin Heidelberg, Springer-Verlag.
- LUI, M., WILLIAMS, D. & PEDERSEN, S. (2002) Alien Rescue: A Problem-Based Hypermedia Learning Environment for Middle School Science. *Journal of Educational Technology Systems*, 30, 255-270.
- MAYER, R. E. (2003) The promise of multimedia learning: using the same instructional design methods across different media. *Learning and Instruction*, 13, 125-139.
- MAYER, R. E. & MORENO, R. (2002) Aids to computer-based multimedia learning. *Learning and Instruction*, 12, 107-119.
- MORENO, R. & MAYER, R. E. (2000) Engaging Students in Active Learning: The Case for Personalized Multimedia Messages. *Journal of Educational Psychology*, 92, 724-733.
- NULDEN, U. (2001) e-ducation: research and practice. *Journal of Computer Assisted Learning*, 17, 363-375.
- PEDERSEN, S., LUI, M. & WILLIAMS, D. (2002) Alien Rescue: Designing for Student-Centered Learning. *Educational Technology* 42, 11-14.
- PLASS, J. L., CHUN, D. M., MAYER, R. E. & LEUTNER, D. (2003) Cognitive load in reading a foreign language text with multimedia aids and the influence of verbal and spatial abilities. *Computers in Human Behavior*, 19, 221-243.
- PLOETZNER, R. & LOWE, R. (2004) Dynamic visualisations and learning. *Learning and Instruction*, 14, 235-240.
- SCHWAN, S. & RIEMPP, R. (2004) The cognitive benefits of interactive videos: learning to tie nautical knots. *Learning and Instruction*, 14, 293-305.
- SEDIG, K., ROWHANI, S. & LIANG, H.-N. (2005) Designing interfaces that support formation of cognitive maps of transitional processes: an empirical study. *Interacting with Computers*, 17, 419-452.

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